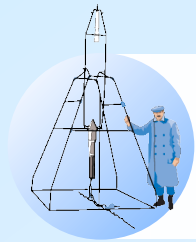


Embedded Thermal Control for Spacecraft Subsystem Miniaturization

Jeffrey R. Didion
Senior Thermal Engineer
Manager, Nanotechnology Facility

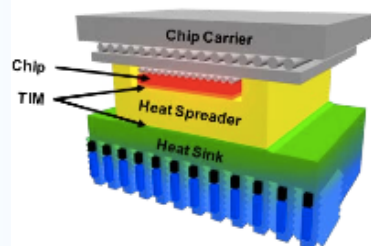




Program Overview

Optimize Spacecraft Mass Power and Volume

- Develop and Validate component, board and enclosure level intelligent embedded thermal control subsystems to enable:
 - CubeSat/SmallSat Electronics Bus
 - High Performance Computing
 - On-board Spacecraft Electronics
 - Power Electronics and RF Arrays



Remote Cooling

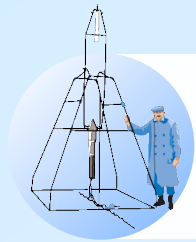
Thermal management must be embedded, like power delivery, in the chip/package technology



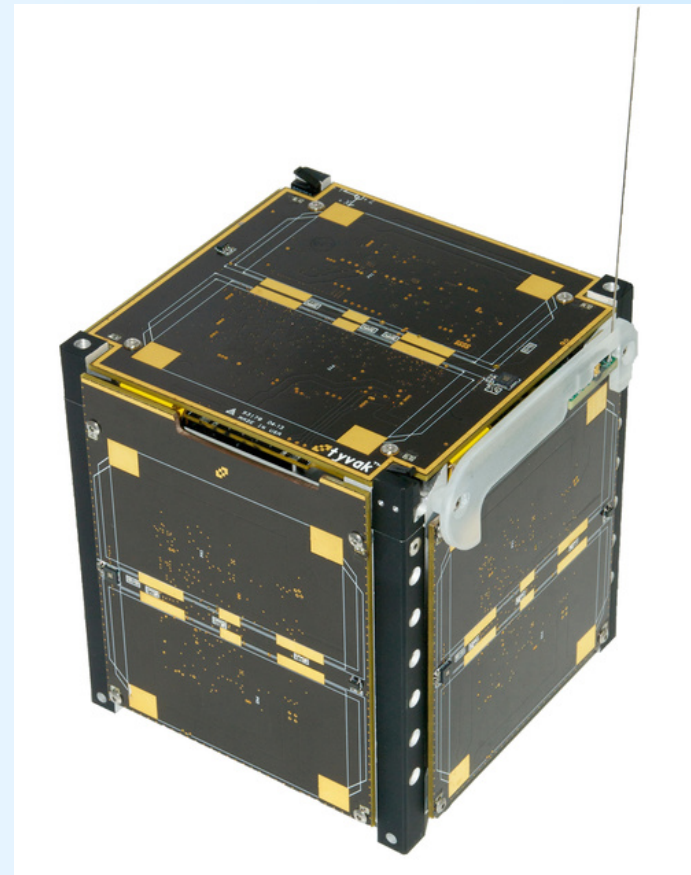
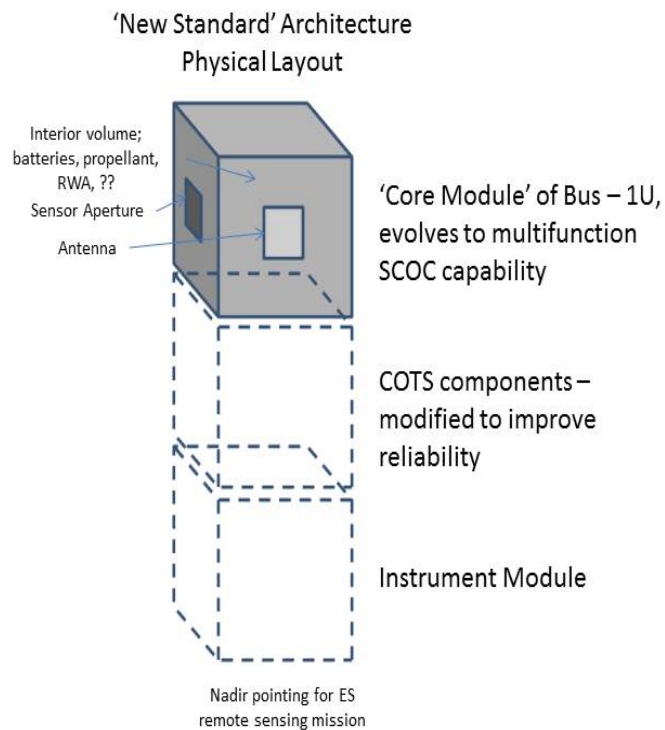
Embedded Cooling

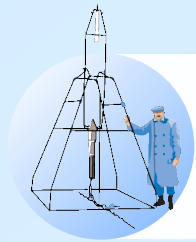
Courtesy Dr. Avram Bar-Cohen
Director, DARPA Thermal Management



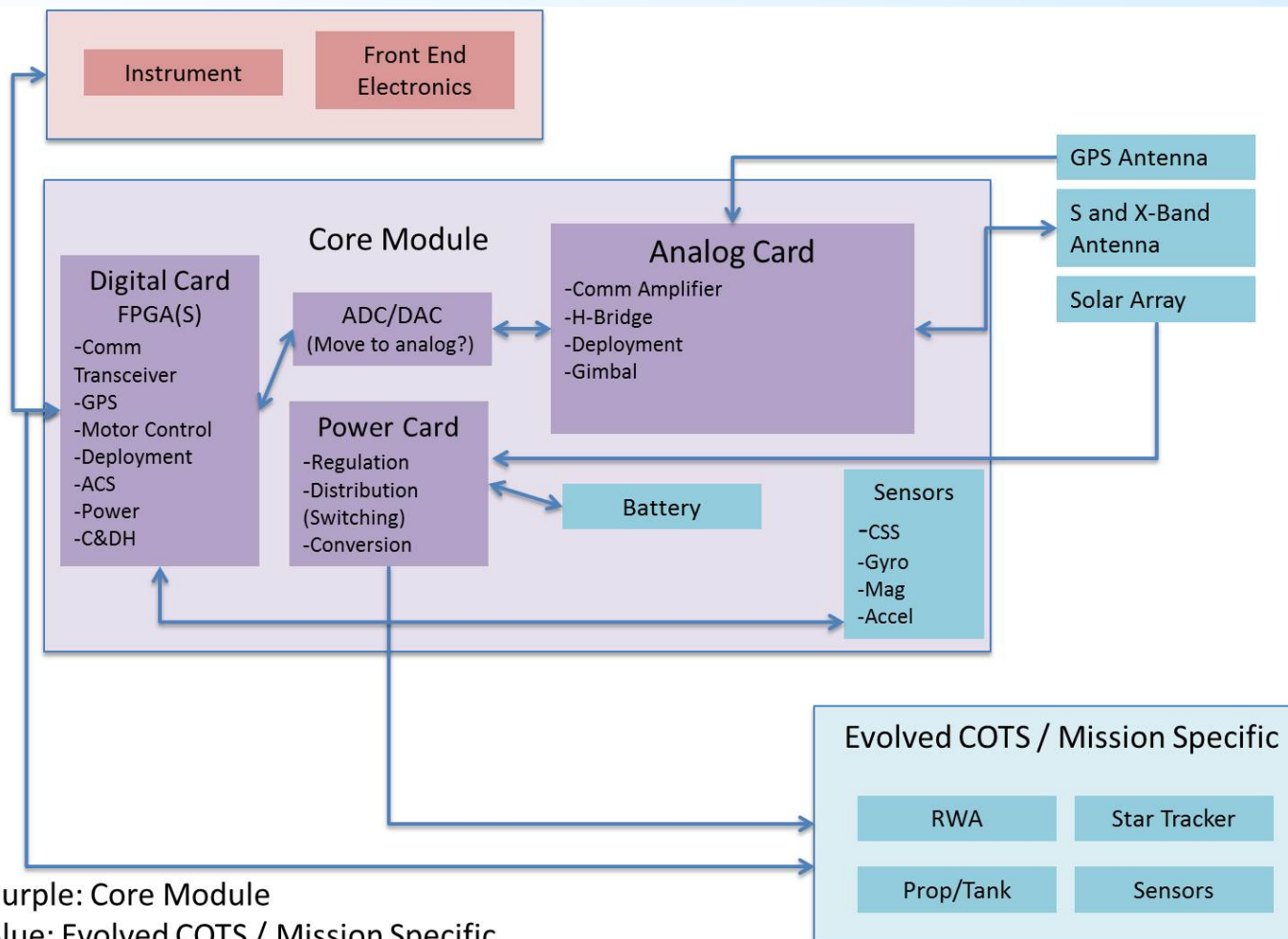


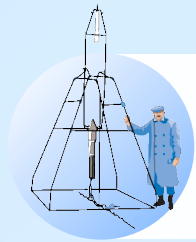
AETD CubeSat Concept





AETD CubeSat Instrument Bus





Technical Challenge

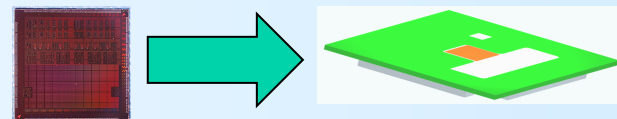
Challenge: Miniaturized, 3-D Electronics Packaging at Component, Board and Subsystem

3-D packaging Schema: Increase heat generation and heat flux

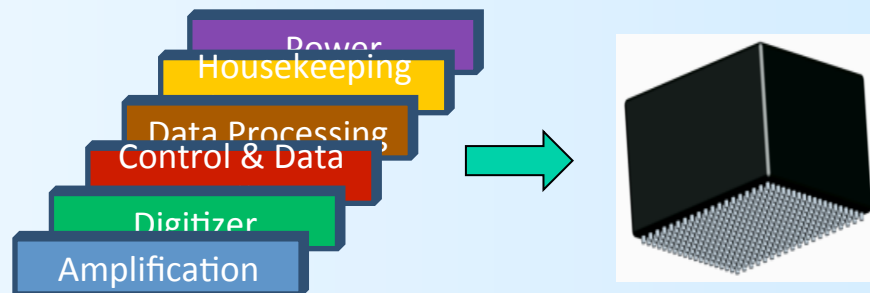
- System/Spacecraft on a chip (SoC)
- Stacked chip based components
- Embedded components on electronics board
- 3-D board packaging

Embedded EHD Thermal Control Subsystems:

- Electrical based: nano- to meso-scale phenomena
- Embedded Hardware:
 - Chip level (silicon)
 - Electronics board level (additive manufacturing/advanced materials)
- Mass and Volume Savings



Embedded SoC



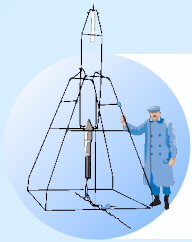
Electronics Bus



Programmatic Overview

- **Technical Approach**
 - **Fundamental Research:**
 - *Electrically Driven Thin Film Boiling* ISS Fluids Physics Program
 - *Self-Sensing Thermal Management Using nano-enhanced Polymers* NSTRF Program
 - **Hardware Development:**
 - Hybrid EHD/Capillary Chip
 - CubeSat/SmallSat Electronics Bus
 - Additive Manufactured Electronics Board/Enclosure
 - **Hardware Validation:**
 - Variable Gravity (FY14 campaign TBD)
 - RockSat-X Sounding Rocket (w. Univ. of Nebraska 8/14)
 - STP-H5 (FY16 Launch)
 - Space Station Microgravity Science Glovebox (~ FY17)

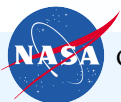


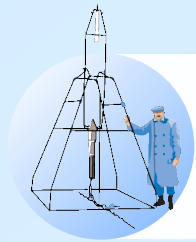


Technical Overview

Scalable Phenomena with Intelligent Capabilities

- Chip/Component Level EHD/Capillary Embedded Devices
- EHD Thin Film Boiling Experiment
- Advanced Manufactured Structures
 - Composite plates e.g. enclosures
 - Additive manufactured multi-functional plates
- Self-Sensing Thermal Management Using Nano-enhanced Polymers
- Numerical Techniques (New Initiatives)
 - Thermal-Mechanical Optimization
 - Electric Field Analysis
 - Systems of Systems Optimization

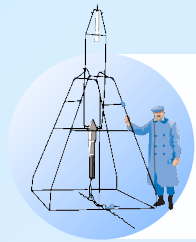




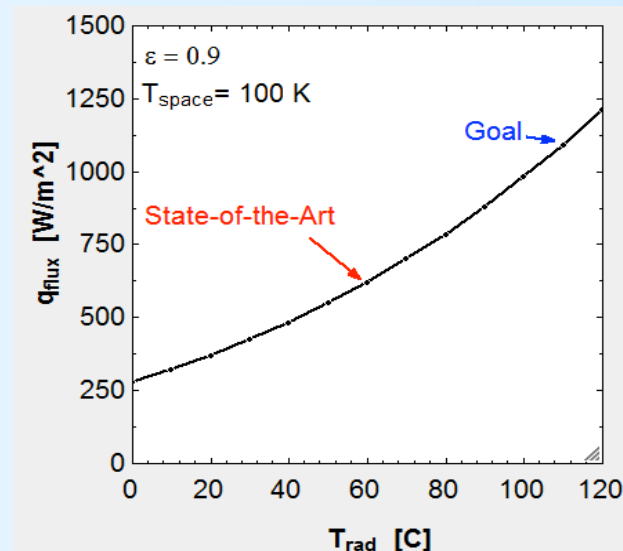
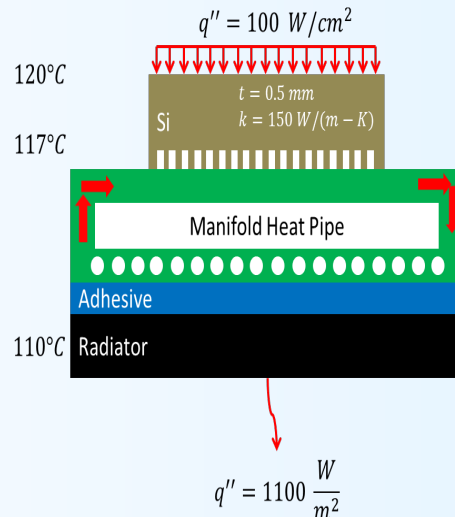
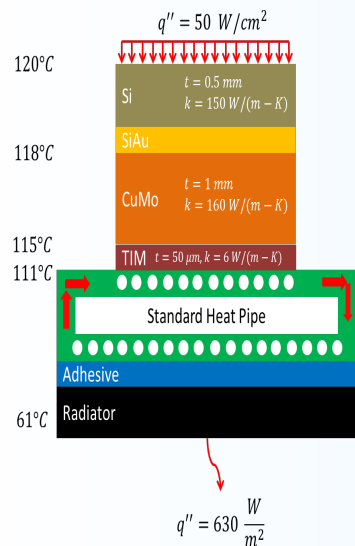
Collaborators & Support

- **NASA GSFC: (IRAD & CIF)**
 - Matthew Showalter/547: Advanced Manufacturing
 - Franklin Robinson/545: Lead Engineer
 - Mario Martins/EDGE Space Systems: Systems Engineer
 - Timothy Miller/553: Micro-scale Fabrication
- **University Research Partners**
 - Prof. Jamal Seyed-Yagoobi, WPI: EHD Phenomena
 - Prof. Hugh Bruck, UMD: Advanced Materials; Sensors
 - Prof. Michael Ohadi, UMD: Small & Smart Thermal Systems
- **External Partners/Sponsors**
 - NASA HQ: ISS Thin Film Boiling Experiment
 - NSTRF Program: Elizabeth Ann Sauerbrunn, Univ. of MD.
 - USAF Space Vehicles Directorate: Experimental Evaluation of EHD Conduction Pumping Electrodes for Integrated Thermal Control of Grid Stiffened Panel
 - Center for Environmental Energy Engineering Consortium (UMD/CEEE) Membership





Chip Embedded Thermal Control



EHD/Capillary Hybrid:

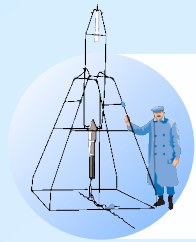
Less Mass/fewer components

Lower thermal resistance

High heat rejection temperature

More Effective Radiator (see figure on right)





EHD Thin Film Boiling Experiment

Objective:

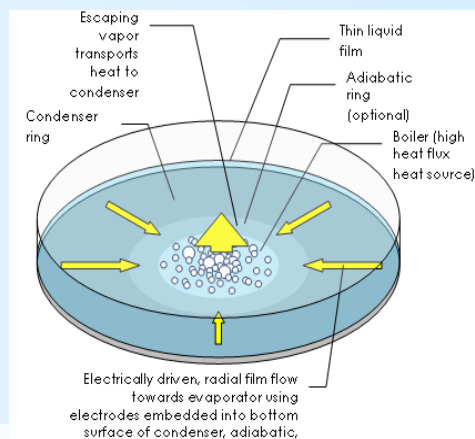
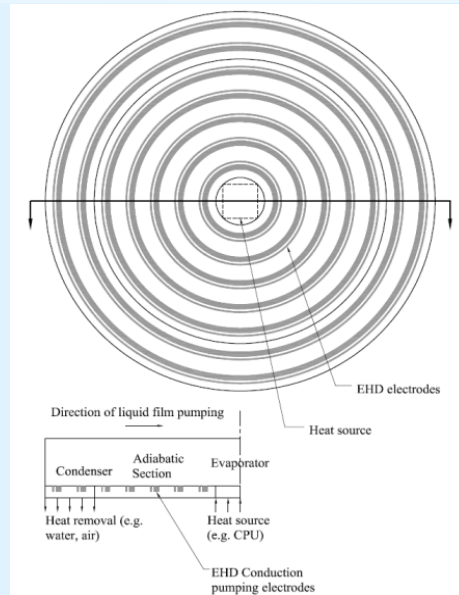
- ♦ Characterize the effects of gravity on the interaction of electric and flow fields in the presence of phase change specifically pertaining to:
 - The effects of microgravity on the electrically generated two-phase flow.
 - The effects of microgravity on electrically driven liquid film boiling (includes extreme heat fluxes).
- ♦ Electro-wetting of the boiling section will repel the bubbles away from the heated surface in microgravity environment.

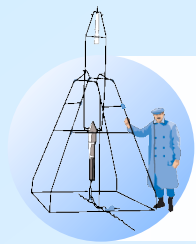
Relevance/Impact:

- ♦ Provides phenomenological foundation for the development of electric field based two-phase thermal management systems leveraging EHD, permitting optimization of heat transfer surface area to volume ratios as well as achievement of high heat transfer coefficients thus resulting in system mass and volume savings.
- ♦ EHD replaces buoyancy or flow driven bubble removal from heated surface.

Development Approach:

- ♦ Conduct preliminary experiments in low gravity and ground-based facilities to refine technique and obtain preliminary data for model development.
- ♦ ISS environment required to characterize electro-wetting effect on nucleate boiling and CHF in the absence of gravity.
- ♦ Will operate in the FIR – designed for autonomous operation.





EHD Thin Film Boiling Experiment

Current Status:

- ◆ Conducted variable gravity flight campaign (September 2013)
- ◆ The experiment functioned reliably and the electrically driven flow resulted in heat transfer enhancement.
- ◆ Gained important scientific understanding of liquid film boiling with presence of electrical field in absence of gravity.
- ◆ Prepared two publications of variable gravity results; two presentations in international conferences.
- ◆ Science Concept Review for ISS Experiment – June/July 2014



Figure 1: EHD Variable Gravity Flight Package

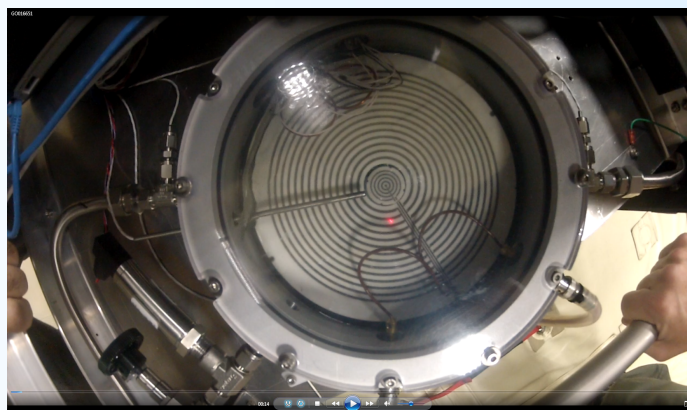


Figure 2: Experiment in operation during 0g (liquid film boiling driven by EHD conduction pumping)

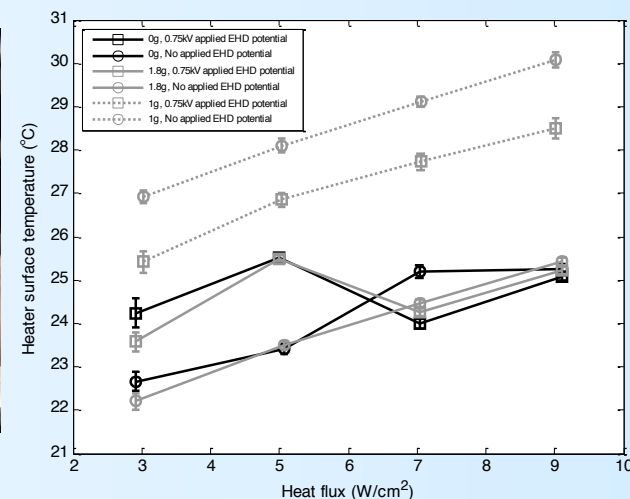
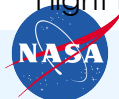
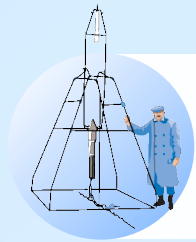


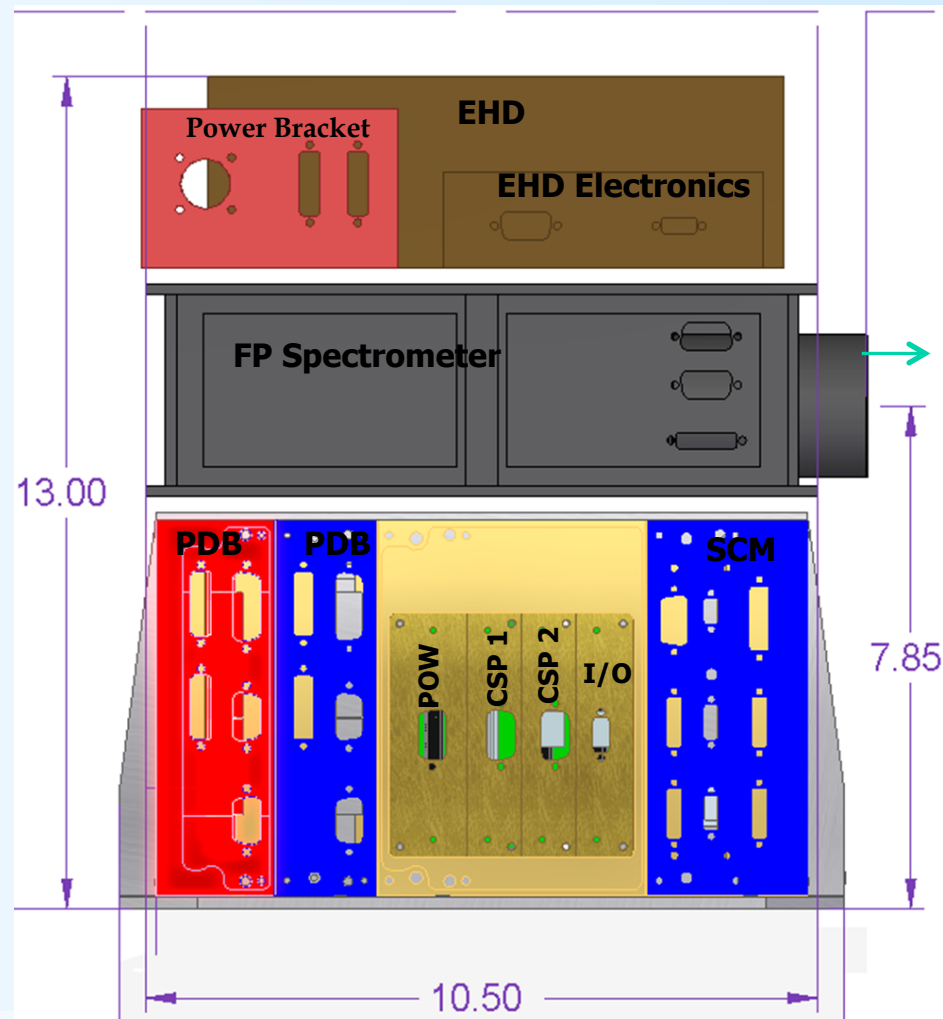
Figure 3: Experimental results

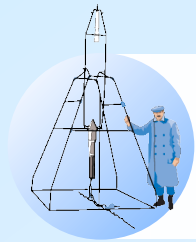




STP-H5 EHD Experiment

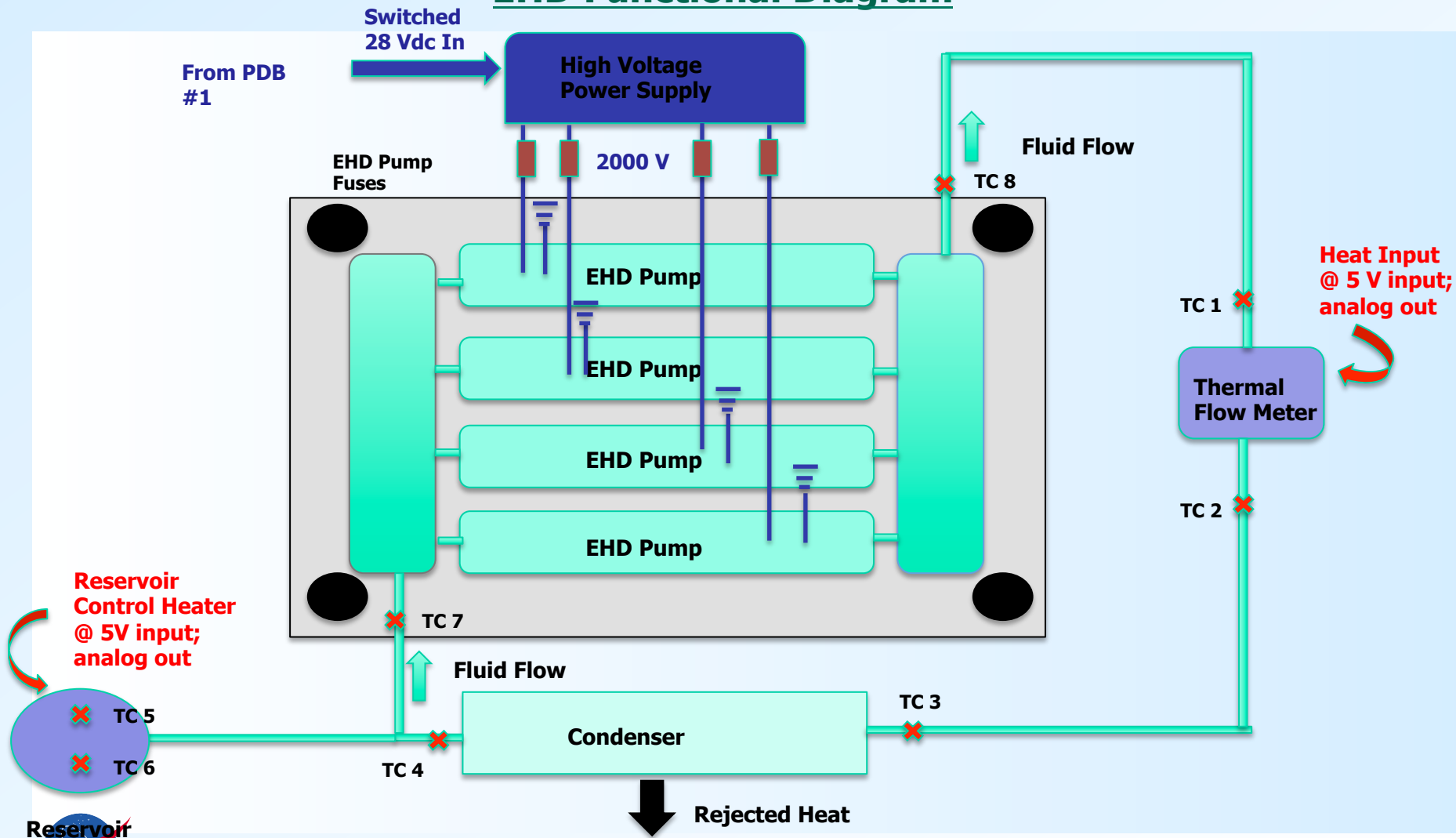
- DoD Payload to demonstrate space technology
- Launch early 2016
- Experiment Delivery in Spring 2014
- EHD Experiment to demonstrate long term operation of EHD pumps for multifunctional structures

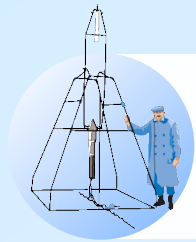




STP-H5 EHD Experiment

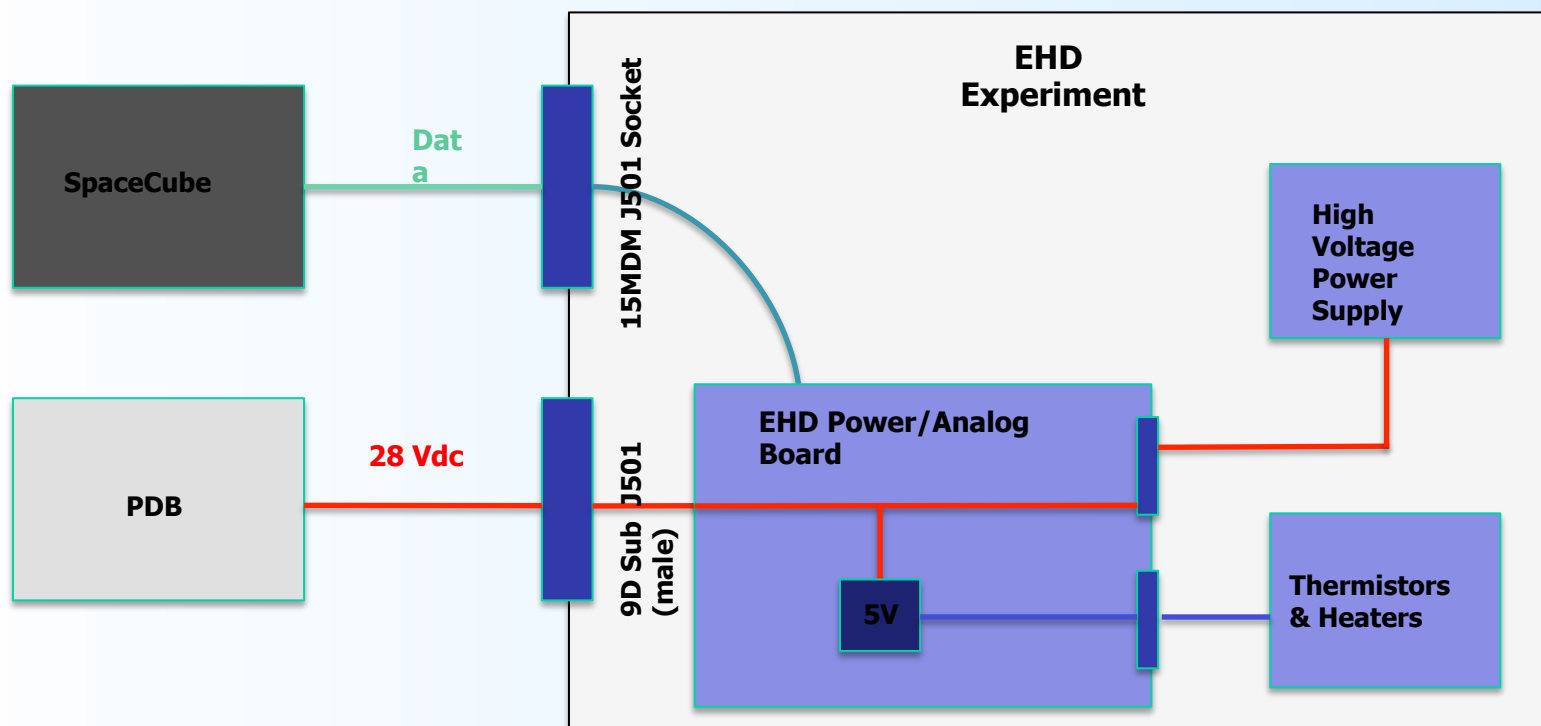
EHD Functional Diagram

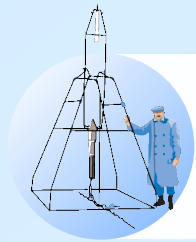




STP-H5 Experiment

EHD Power Distribution





Multifunctional Structures

USAF Multifunctional Plate

- Design EHD electrodes
- Integrate EHD electrodes into channels
- Environmental Testing in Thermal Vacuum Chambers at GSFC
- CFRP Composite Plate
 - Approximately 50% density of aluminum
 - Non-conductive substrates for EHD systems
 - Structural-Thermal functions

